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UCRL-ID-151403

Hyperspectral Image-Based Broad Area Search (HIBAS) LDRD Final Report Summary

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January 7, 2003

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Summary

Background and Problem Statement

Two of the more important tasks faced by image analysts are broad area search and site monitoring. In each case, the objective is to detect occurrences of targets of interest (e.g., buildings, mobile targets of military significance, etc.). In broad area search, large swaths of countryside are imaged. In site monitoring, a number of smaller areas of interest are imaged multiple times. The crisis currently facing image analysts lies in their inability to analyze massive volumes of remotely sensed imagery in a time critical fashion. The problem has become more critical with technological advances that have enabled images of increasing size, resolution and dimensionality (such as monochrome images at higher spatial resolution -e.g., Digital Globe imagery - and hyperspectral images at higher spectral resolution) to be rapidly acquired.

Purpose of the Project

The key to addressing the time criticality issue is to automate the target cueing task and to present human analysts with regions of potential interest that cover only a small percentage of the collected area. The purpose of the *Hyperspectral Image-Based Broad Area Search (HIBAS)* LDRD project was to develop insight into robust image processing and target signature analysis algorithms for automating the target cueing task.

Phases of the Project

HIBAS was divided into image segmentation and target signature analysis phases. Image segmentation is a process by which a computer automatically divides an image into regions containing pixels that logically belong together, much as a human analyst would if there were sufficient time. Target signature analysis is a process by which a computer automatically compares the spatial and spectral properties of an extracted region or set of regions to the spatial and spectral properties of a target of interest, in order to determine whether or not to flag it as a potential target (i.e., to set off an alarm and make it a target cue). *Automatic target cueing (ATC)* can be conducted using either a *"spatial-first"* or a *"spectral-first"* pipeline, depending on the application. In the "spatial-first" approach, image segmentation is followed by spatial signature analysis and then spectral signature analysis. The image is segmented, groups of regions that satisfy the target spatial constraints are found, and then spatial cues that satisfy the target spectral constraints are found. In the "spectral-first" approach, spectral signature analysis is followed by segmentation and then spatial signature analysis. The incoming image is first converted into an image of detected signal or anomaly strengths using spectral signature analysis. The image of spectral signal strengths is then subjected to segmentation, and regions that satisfy the target spatial constraints are found.

Accomplishments

HIBAS was originally proposed as a three year LDRD project. The first years of the project were to be devoted to segmentation and spatial signature analysis. The last year was to be devoted to development of an end-to-end ATC capability with a spectral signature analysis component. HIBAS was limited to two years, in light of a larger proposed follow-on project. Most of the HIBAS accomplishments (see below) are thus oriented towards image segmentation results, with less emphasis on signature analysis (in particular, spatial signature analysis). The two year effort resulted in six conference papers ([1]-[6]) plus one record of invention ([7]). Two of the conference papers ([5]-[6]) describe the important segmentation results, and are attached.

In the area of image segmentation, variations and extensions of two well-established algorithms were implemented. The first algorithm, referred to as *Multi-Band Region Growing (MBRG)*, is based on a numerical procedure known as region growing [5]. The second algorithm, referred to as *K-Means Re-Clustering (KMR)*, is a variation of the K-Means algorithm, and is based on unsupervised pixel classification [6]. These two algorithms capture the two most dominant approaches to image segmentation in use today, and are based on competing principles.

Most (if not all) segmentation algorithms have one (and in some cases, more than one) input parameter (i.e., a "knob") whose setting profoundly affects the outcome of the segmentation process. For example, in KMR, K (the number of pixel classes) must be set, and in MBRG, a spectral similarity threshold for region growing must be set. In practice, these parameters are either set on a trial and error basis, or, in very limited cases, they can be safely set to fixed values that are easy to establish. However, in order to automate the image segmentation process, it is necessary to establish a framework for automatically choosing appropriate parameter settings. A self-calibration framework for segmentation of single and multi-band images (such as hyperspectral images) that automatically chooses appropriate algorithm parameter settings was developed [5]. The framework is generic in the sense that it can imbed any core segmentation algorithm. The framework was tested on hyperspectral remotely sensed images with varying degrees of clutter from three different sensors (namely AVIRIS, HIRIS and SHARP), as well as on various monochrome images.

In the area of spatial signature analysis, a simple discriminator based on shape features of regions was developed. It was shown that this approach is prone to unnecessarily high false alarm rates. An alternative spatial signature analysis algorithm based on *area correlation* (a form of *2D template matching*) was developed. This method is expected to be less susceptible to high false alarm rates, but was not vetted (due to lack of time).

What was Learned

A great deal of knowledge and insight was gained as a result of executing the HIBAS project plan over two years. The following insights, results and future directions apply to image segmentation:

- Image segmentation quality (both subjective and quantitative) does *not* typically appear to be highly correlated with spectral resolution. Regarding hyperspectral images, since computational complexity increases with spectral resolution, it is thus often best to apply segmentation to images that have been blurred to modest spectral resolution (say tens of spectral bands).
- Segmentation quality appears to be affected more by choice of algorithm parameter settings than by choice of algorithm.
- The current self-calibration strategy for setting algorithm parameter values often produces segmentations that are reasonably close to what a human analyst would produce manually. However, there is often no one parameter setting that produces a segmentation containing most or all regions and objects that a human analyst can readily detect. Instead, these regions and objects of interest often all exist not in any one segmentation, but across several segmentations corresponding to different parameter settings. It will thus be important to develop a technique for automatically merging segmentations corresponding to different levels of coarseness or granularity.
- In regard to K-Means type algorithms for image segmentation, larger numbers of spectral classes (e.g., K values beyond 5 or 10) often cause images to be over-segmented. The most effective segmentations are often achieved using modest values of K at modest spectral

resolutions with relaxed K-Means convergence criteria. These segmentations happily have high associated computational efficiencies.

The following insights, results and future directions apply to spatial signature analysis:

- Of three approaches to spatial signature analysis, namely *shape feature-based analysis*, *template matching* and *model matching* (in order of increasing sophistication), model matching has the greatest potential for success because it uses the greatest amount of information about the target. However, since 3D representations of objects are not typically acquired by imaging sensors, template matching of 3D projections onto 2D image planes provides a useful compromise. Shape-feature based analysis, though simple, is prone to unnecessarily high false alarm rates.
- Whether to apply a "spatial-first" or a "spectral-first" approach to automatic target cueing is dictated by the nature of the input data and the application. A "spectral-first" approach is called for when the spectral signatures of the target are easily to detect in the image. However, if the spectral signatures of the target are non-specific, concealed or otherwise difficult to detect, a "spatial-first" approach may be better.

Publications and Documents

[1] David W. Paglieroni and Dwight E. Perkins, "Spatial Constraints on Segmented Regions for Target Cueing in Hyperspectral Images", Proc. Military Sensing Symposium on Passive Sensors, March 5-7, 2001, Vienna, VA.

[2] David W. Paglieroni and Dwight E. Perkins, "Automatic Extraction of Spectrally Homogeneous Closed Pixel Clusters for Target Cueing in Hyperspectral Images", Proc. SPIE 46th Annual Meeting, The International Symposium on Optical Science and Technology, San Diego, CA, July 29 - August 3, 2001.

[3] Raymond Wong, Gary E. Ford and David W. Paglieroni, "K-Means Re-Clustering: An Alternative Approach to Automatic Target Cueing in Hyperspectral Images", SPIE Aerosense, 1-5 April 2002, Orlando, FL.

[4] David W. Paglieroni, "Algorithms and a Methodology for Gas Species Identification Developed on the HIRIS Program", 2002 MSS Specialty Group Meeting on Passive Sensors, April 22-26, 2002, Charleston, SC.

[5] David W. Paglieroni, "A Self-Calibrating Multi-Band Region Growing Approach to Segmentation of Single and Multi-Band Images", SPIE Photonics West, Optical Engineering at LLNL, to appear, Jan. 2003.

[6] Alan Meyer, David W. Paglieroni and Cyrus Astaneh, "K-Means Re-Clustering: Algorithmic Options with Quantifiable Performance Comparisons", SPIE Photonics West, Optical Engineering at LLNL, to appear, Jan. 2003.

[7] David W. Paglieroni, "Generic and Automatic Self-Calibration Framework for Image Segmentation", Lawrence Livermore National Laboratory, Record Of Invention, LLNL File No. IL-11110, received November 19, 2002.